Hydraulic-Fracture Test Apparatus and Procedure For Determining Aggregate Durability

STUDY PROPOSAL FOR RESEARCH PROJECT 225-1

APRIL 1994

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
Mario M. Cuomo, Governor/John C. Egan, Commissioner

A. Identification

Study Title:	HYDRAULIC-FRACTURE TEST APPARATUS AND PROCEDURE FOR DETERMINING AGGREGATE DURABILITY Research Project 225-1
Agency:	Engineering Research and Development Bureau New York State Department of Transportation State Campus, Albany, New York 12232
Principal Investigator:	Dan E. McAuliffe Civil Engineer I
Research Supervisor:	Wei-Shih Yang Engineering Research Specialist II

B. Problem Statement

Current aggregate durability tests (magnesium-sulfate and freeze-thaw) are labor- and time-intensive. A simpler, faster, more accurate test is desirable. As a "product" of the Strategic Highway Research Program (SHRP), a hydraulic-fracture apparatus and test procedure were developed by the University of Washington (see Appendix). This procedure -- SHRP Product 2002 -- subjects coarse aggregate samples to 8 MPa of water pressure, and then quickly releases the pressure, creating significant internal forces within the aggregate's pore structure. Its resistance to fracture under these conditions should be an indicator of its freeze-thaw resistance. Unfortunately, equipment for this new test was designed with 16 threaded rods and nuts to secure the cover to the vessel containing the aggregate sample, and the cover must be removed several times during the test to observe the sample. This makes the test apparatus cumbersome and the procedure labor-intensive. The New York State Department of Transportation is proposing a simplified test chamber and an automated test procedure. In addition to the problems with the SHRP test chamber and procedure, analysis of test results to determine aggregate durability is also in question. Upon revision of the test apparatus and procedure, it will be necessary to relate the hydraulic-fracture test to the magnesium-sulfate and freeze-thaw tests, and to actual aggregate performance.

C. Objectives

The study has four primary objectives:

1. Develop a simplified test chamber. The SHRP device is cumbersome, and will be difficult to assemble/disassemble as required for the test.

2. Develop an automated test procedure, to reduce the time required to perform the SHRP test.

3. Interpret results from the new test procedure and apparatus.

4. Determine any relationships between the hydraulic-fracture test and a) the magnesium-sulfate test, b) the freeze-thaw test, and c) actual aggregate performance. The expected speed of this procedure and a direct correlation of its results with the older procedures would be a major improvement.

D. Background

The Department's specifications for coarse aggregates require that they be tested for durability. Currently, the Department uses the magnesium-sulfate and freeze-thaw tests, but they have several drawbacks — they are time-consuming, results are hard to repeat, variation among labs is significant, and procedures must be followed strictly.

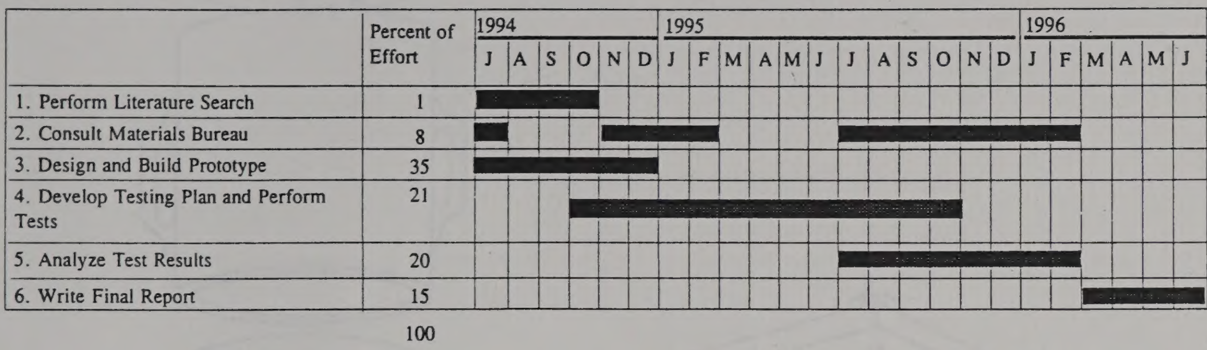
E. Benefits

The freeze-thaw and magnesium-sulfate tests require up to six weeks to complete, making approval of coarse-aggregate sources slow and costly. Both tests are also extremely susceptible to procedural error. Finally, test repeatability and reliability are such that they should all be performed by the same lab. The proposed hydraulic-fracture test would be quick — a day or two — allowing fast determination of aggregate durability and testing of more sources, reducing labor costs associated with determining aggregate durability, virtually eliminating procedural errors, and increasing the repeatability and reliability of aggregate durability tests, thus allowing private labs with the necessary equipment to perform the work.

F. Implementation

Once the prototype test apparatus and procedure are ready, a cost-benefit analysis will be performed to determine if use of this test would be cost-effective. If so, the research results will be ready for use when the project is completed. The Materials Bureau will assist in finalizing the proposed hydraulic-fracture test procedure, and issuing the necessary engineering bulletins to allow use of the new procedure. Additionally, plans and specifications for the hydraulic-fracture test apparatus will be submitted as part of the test procedure. Cost of implementation will consist of the equipment and training costs for each region. It is estimated

Figure 1. Work-time schedule.



apparatus will cost $69,000. Training will include two technicians in the Main Office being instructed for one or two days in operation of the test apparatus at an approximate cost of $120 each.

G. Work Plan

The work proposed will proceed approximately as shown in Figure 1. A study period of two years is proposed, with tasks to accomplish the following objectives:

1. Perform Literature Search
   The literature will be searched to identify available resources and provide background material for coarse aggregate durability testing.

2. Consult with Materials Bureau
   The Materials Bureau will provide the geology expertise required to analyze preliminary testing results and determine their validity. They will also provide guidance as to whether the "new" test may be used for screening and/or replace either or both the magnesium-sulfate and the freeze-thaw tests.

3. Design and Build Prototype Testing Chamber
   A test chamber is needed that can be quickly assembled and disassembled, and used in an automated test procedure. Figure 2 shows the proposed test chamber design, and Figure 3 the automated test apparatus and procedure.

4. Develop Testing Plan and Perform Preliminary Tests
   A modified procedure will be developed to test various coarse aggregates and determine any correlations between the hydraulic-fracture test and the two older tests. In addition, the plan will search for any correlations between the new test and actual coarse aggregate performance. First, two coarse aggregates of the same rock type, one having excellent durability and the other poor durability, will be tested using the modified test procedure. The statistician will be consulted to determine the number of tests necessary to achieve various levels of reliability based on the results of the preliminary tests.

Figure 2. Details of proposed apparatus.

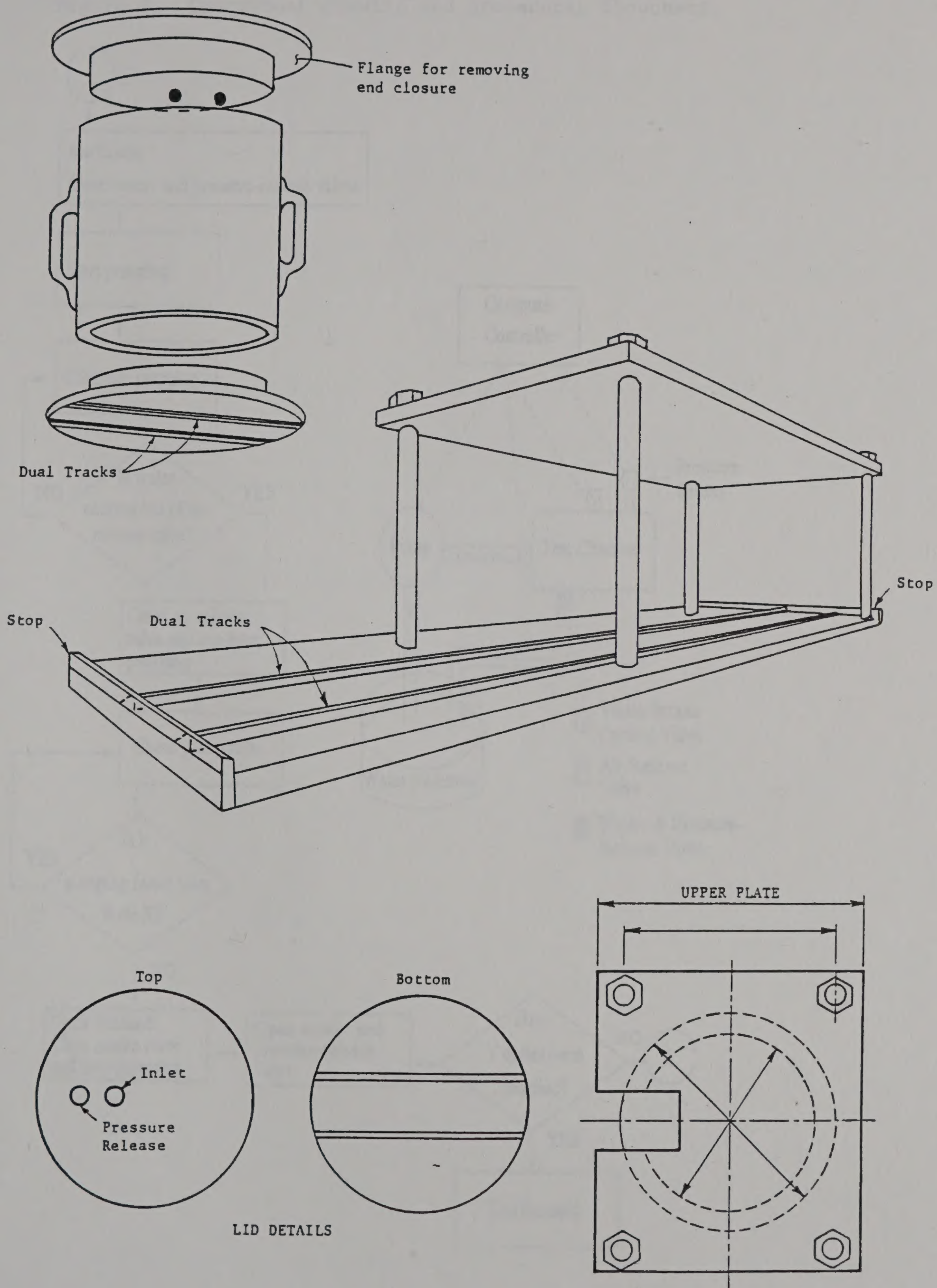
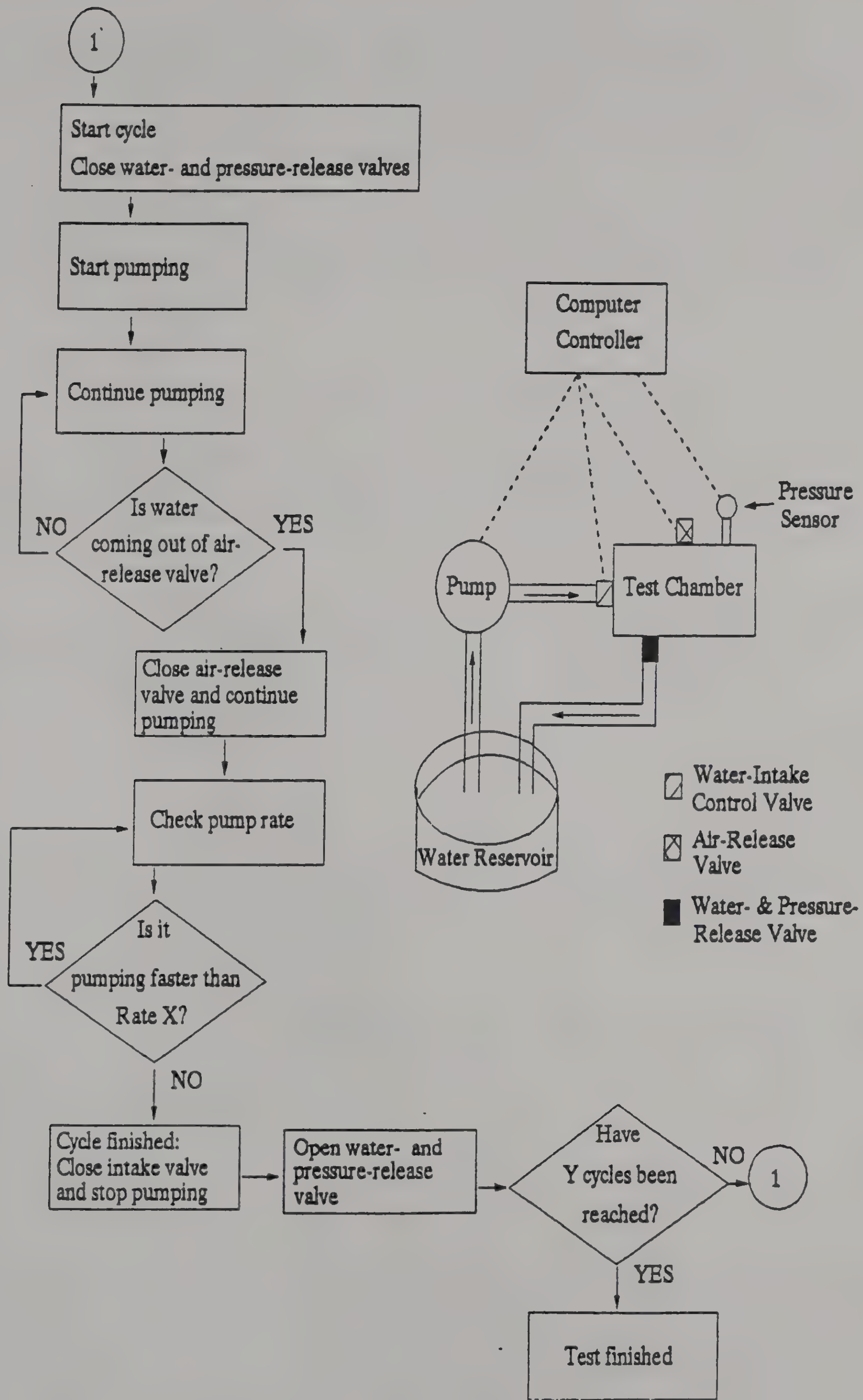


Figure 3. Conceptual drawing and procedural flowchart.



5. Analyze Test Results and Develop New Test Procedure
   Data collected will be analyzed to determine if the hydraulic-fracture test predicts actual performance, and to find correlations with the two older tests. Once any correlations are found, a new materials testing procedure using the hydraulic-fracture test apparatus will be formulated.

6. Write Final Report
   A report will be prepared summarizing findings of the preliminary testing, the degree of automation achieved, repeatability of the test, and outlining the new procedure.

H. Personnel and Budget Estimates

This study will be conducted under general supervision of Dr. Robert J. Perry, Director of Engineering Research and Development, with technical guidance by Wei-Shih Yang, Engineering Research Specialist II, Materials/Pavements Section. The budget is estimated as shown in Tables 1, 2, and 3.

Table 1. Skill level and project duration in person-weeks.

Skill	FY 1994						FY 1995												FY 1996					
Level	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
SI	3	3	3	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SET	-	-	-	-	-	-	2	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-	-	-
CE I	1	1	1	1	1	1	1	1	-	-	-	-	2	2	2	2	2	2	2	2	3	3	3	3
LED	3	3	3	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AS	-	-	-	-	-	1	1	1	1	-	-	-	1	1	1	1	1	-	-	-	-	-	-	-
AMA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
EG II	1	-	-	-	-	1	1	1	1	-	-	-	2	2	2	2	2	2	2	2	1	1	1	1
ERS II	3	2	2	-	1	3	1	-	-	-	-	-	1	-	1	-	1	-	1	-	1	1	1	1

Note: SI = Student Intern, SET = Senior Engineering Technician, CE I = Civil Engineer I, LED = Laboratory Equipment Designer, AS = Associate Statistician, AMA = Associate Materials Analyst, EG II = Engineering Geologist II, ERS II = Engineering Geologist II.

Table 2. Function vs. skill level.

	Person-Weeks							
Function	SI	SET	CE I	LED	AS	AMA	EG II	ERS II
1. Perform Literature Search	--	--	1	--	--	--	1	--
2. Consult Materials Bureau	--	--	5	--	--	--	5	2
3. Design and Build Prototype	18	--	4	18	--	--	--	10
4. Develop Testing Plan and Perform Tests	--	14	4	--	4	--	4	3
5. Analyze Test Results	--	--	10	--	5	--	11	2
6. Write Final Report	--	--	12	--	--	2	4	3
Total Person-Weeks	18	14	36	18	9	2	25	20
Estimated Cost	$9,985	$8,544	$25,065	$13,643	$7,420	$2,030	$26,676	$22,954
Total Personal Service								$116,318

Table 3. Budget estimate.

Item	FY 94-5	FY 95-6	FY 96-7	Total
Personal Service	$33,420	$51,926	$30,972	$116,318
Equipment	65,000	2,000	2,000	69,000
Total Cost				$185,318

APPENDIX
WASHINGTON STATE HYDRAULIC-FRACTURE TEST PROCEDURE IN AASHTO FORMAT

NOTE: The cylinder currently used and proposed is 10 in. high

Proposed Method of Test
for

Hydraulic Fracture of Coarse Aggregate

1. SCOPE

1.1 This test method assesses the resistance of aggregates to fracture by using a sudden increase in pressure gradient to expel water from aggregate pores. The procedure assists in the identification of aggregates that may cause deterioration in concrete when exposed to repeated cycles of freezing and thawing (D-cracking).

1.2 This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety problems associated with its use. It is the responsibility of whosoever uses this procedure to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*

T 2	Sampling Aggregates
T 161	Resistance of Concrete to Rapid Freezing and Thawing
M 92	Wire Cloth Sieves for Testing Purposes
M 231	Weights and Balances Used in The Testing of Highway Materials

2.2 *ASTM Standards*

C 702	Method for Reducing Field Samples of Aggregate to Testing Size
D 3152	Standard Test Method for Capillary Moisture Relationships for Fine-Textured Soils by Pressure-Membrane Apparatus
D 3665	Practice for Random Sampling of Construction Materials

3. SIGNIFICANCE AND USE

3.1 As noted in the scope, the procedure described in this method is intended to aid in the identification of D-cracking susceptible aggregates. Aggregates that exhibit a high

percentage of fracturing under repeated pressurization cycles are considered to be more likely to cause D-cracking in field applications.

3.2 The relative short time (approximately eight working days) required for completion of this procedure makes it appropriate for use as a screening test to identify questionable aggregates that require additional testing (such as AASHTO T 161) prior to approval.

3.3 This method is sensitive to the size of the aggregate pieces, and may be appropriate for identifying maximum aggregate size reductions necessary to avoid D-cracking.

3.4 This method is also sensitive to the number of nondurable particles in a sample, and may be appropriate for determining the percentage of durable aggregate that must be blended with nondurable aggregate in order to produce a blend that provides acceptable performance.

4. APPARATUS

4.1 *Tumbling Apparatus:*

4.1.1 The tumbling apparatus (hereafter referred to as the tumbler) shall consist of a rubber drum for holding the sample and a motorized drive unit.

NOTE 1 - A suitable tumbler is available commercially for polishing rocks. Various sizes are available.

4.1.2 The rubber drum shall have inside dimensions of approximately 170 mm (6-3/4 in.) diameter by 200 mm (8 in.) deep. The inside shall be faceted to assist in the tumbling of the aggregate pieces. The drum shall have a removable cover to facilitate placing the sample in the drum, and the cover should not interfere with the rotation of the drum when in the motorized drive unit.

4.1.3 The motorized drive unit shall be capable of rotating the drum on its side at a rate of 30 ($\pm$5) revolutions per minute.

4.2 *Pressurization Apparatus:*

4.2.1 The pressurization apparatus shall consist of a pressure chamber able to safely withstand operating pressures of 10,000 kPa (1500 psi), a compressed nitrogen source, an adjustable pressure regulator with gauge having an output capacity of up to 10,000 kPa (1500 psi), appropriate valves and fittings to permit filling with water and draining along

with pressurization/rapid pressure release, and a stand to permit a 90° rotation of the pressurization apparatus.

4.2.2 The inside dimensions of the pressure chamber shall be 254 mm (10 in.) diameter by 254 mm (10 in.) high. The chamber shall consist of three pieces: a cylinder with three through holes tapped from the outside, 25 mm (1 in.) from the end, for 3/8 in. NPT, and top and bottom plates, each with a handle for lifting. All pieces shall be at least 25-mm (1-in.) thick. The three tapped holes shall be spaced around the cylinder with the second 22.5° from the first and the third 180° from the first. Grooves in each end of the cylinder should accept an O-ring for sealing. The top and bottom plates should be drilled to clear the high-strength bolts used to hold the chamber shut. A photograph of the hydraulic fracture apparatus is included in Appendix A.

NOTE 2 - A similar pressure chamber is available as a 100 Bar Pressure Membrane Extractor for testing soils in accordance with ASTM D 3152 at pressures up to 10,000 kPa (1500 psi). For use with the Hydraulic Fracture procedure, the 100 Bar Pressure Membrane Extractor should be purchased with a second top plate substituted for the standard bottom plate, and a 254-mm (10-in.) tall cylinder substituted for the standard 51-mm (2-in.) tall cylinder.

NOTE 3 - Shop-built pressure chambers are not recommended due to the difficulty with obtaining pressure-tight seals at the high pressures involved, as well as the hazards associated with high pressures. If a shop-built pressure chamber is used, it should be pressure-certified to provide a safety factor of at least 5 to 1.

4.2.3 The cylindrical part of the pressure chamber shall be fitted with necessary valves and fittings to permit the application of pressure (pressure valve), release of pressure (pressure release valve), filling with water (fill valve), and draining (drain valve). Additional valves and fittings may be provided where appropriate by the equipment manufacturer in order to achieve the necessary pressure-release rate.

The pressure release should be linear with time over a range of 3600 kPa (520 psi). The release rate should be 209,000 kPa/sec. (30,300 psi/sec.) for the linear portion of a pressure-time curve. A typical pressure-time relation showing the linear portion and the release rate is shown in Appendix B.

NOTE 4 - The amount of fracturing produced is sensitive to the release rate, with a release rate of 166,000 kPa/sec (43,000 kPa/sec less than specified in 4.2.3 above) producing consistently less fracturing than with the correct rate. Current investigation is examining the sensitivity of pressure release rate and length of the linear range of the pressure-time relation.

4.2.4 A pressure regulator and gauge that attaches directly to a compressed nitrogen cylinder shall be provided. The regulator shall have a capacity of 10,000 kPa (1500 psi). The gauge shall have a precision of 0.25% of full scale.

NOTE 5 - An appropriate regulator with gauge is available from the manufacturer of the pressure chamber referred to in NOTE 3.

4.2.5 A stand shall be provided to permit rotation of the assembled pressure chamber from horizontal position for filling and assembly to vertical for testing.

4.3 *Drying Oven:*

The drying oven should allow free circulation of air through the oven and should be capable of maintaining a temperature of 121°C ±5°C (250°F ±9°F).

4.4 *Balance:*

The balance should conform to the requirements of AASHTO M 231 for the class of general purpose balance required for the principal sample mass of the sample to be tested.

5. SPECIAL SOLUTIONS REQUIRED

5.1 A solution of alkylalkoxysilane in water (referred to as silane solution) is used in Step 7.3 as part of the sample preparation.

5.2 Appropriate precautions in handling the silane solution should be observed.

NOTE 6 - An appropriate silane solution is available commercially as Enviroseal 40 from Hydrozo, Inc.

NOTE 7 - Some aggregates absorb water at a very rapid rate, which prevents them from fracturing in the following test procedure. The silane treatment described in Step 7.3 reduces the absorption rate by effectively making the aggregates more hydrophobic. This treatment has been demonstrated to have no effect on the hydraulic fracture performance of aggregates with slower absorption rates.

6. SAMPLES

6.1 Representative samples of aggregate sources should be obtained by appropriate means and in accordance with accepted procedures such as AASHTO T 2, and ASTM C 702 and D 3665.

6.2 Samples will be divided into individual size ranges (step 7.1 below). Appropriate size ranges may include passing the 32 mm (1-1/4 in.) but retained on the 19 mm (3/4 in.) sieves and passing the 19 mm (3/4 in.) but retained on the 12.5 mm (1/2 in.) sieves.

6.3 Duplicate specimens may be run to obtain acceptable variability, and sufficient material should be collected in the initial sample to provide the necessary number of particles in each desired size range. Preliminary work has indicated that 600-800 particles in a given size range provides a coefficient of variation of less than 10 percent in the final results.

7. PREPARATION OF TEST SAMPLE

7.1 Separate the sample into appropriate size ranges by sieving to refusal using approved wire screens (AASHTO M 92). Individual specimens should contain sufficient aggregate to fill the pressure chamber.

NOTE 8 - Approximately 15 kg. (33 lbs) are needed for a test specimen in the passing 32 mm (1-1/4 in.) but retained on the 19 mm (3/4 in.) sieve size range. This is approximately 800 particles. The actual amount depends upon the size and shape of the individual particles.

7.2 The aggregate specimens should be thoroughly washed and dried to a constant mass at a temperature of 120°C ±5°C (250°F ±9°F), and allowed to cool to room temperature.

NOTE 9 - Adequate ventilation should be supplied for the following three steps. The use of a fume hood may be appropriate.

7.3 Place the aggregate specimen in the silane solution, making sure that all aggregate pieces are covered. Allow the specimen to remain in the silane solution for 30 (±5) seconds.

7.4 Remove the specimen from the silane solution and allow the excess solution to drain for 5 minutes.

NOTE 10 - Strainers suitable for immersing the aggregate in the silane solution and draining are readily obtainable from restaurant supply sources.

NOTE 11 - The silane solution may be reused if it is placed in a sealed container between uses. The solution should be discarded if it begins to thicken.

7.5 Dry the specimen to a constant mass at a temperature of 120°C ±5°C (250°F ±9° F), and allow to cool to room temperature.

8. PROCEDURE

8.1 Place enough of the specimen into the tumbler to fill it approximately halfway and tumble for 1 minute. Separate out any pieces passing the 9.5 mm (3/8 in.) sieve. Repeat for the remainder of the specimen. Determine the mass to the nearest gram and count the number of pieces retained on the (9.5 mm) (3/8 in.) sieve. Record these numbers as the initial mass and number of particles, m_0 and n_0, respectively.

8.2 Place the specimen into the pressure chamber, and close the chamber as directed in the manufacturer's instructions. Rotate the apparatus from the filling (horizontal) to the testing (vertical) position.

8.3 Close the pressure valve and open the main valve on the nitrogen tank. The pressure regulator should be set to 7930 kPa (1150 psi.).

8.4 Fill the pressure chamber with water in accordance with the manufacturer's instructions. After the water has run from the drain line for approximately 30 seconds, turn off the water supply and close the fill, pressure release, and drain valves.

8.5 Pressurize the chamber for 5 minutes (±5 seconds) by opening the pressure valve. Adjust the pressure regulator as necessary to maintain 7930 kPa (1150 psi.). At about 4-1/2 minutes, close the pressure valve and disconnect the drain line from the pressure release valve.

8.6 After 5 minutes (±5 seconds) of pressurization, *while wearing ear protection*, release the pressure by rapidly opening the pressure release valve.

8.7 Refill the pressure chamber by re-attaching the drain line to the pressure release valve, opening the fill valve, and turning on the water supply. Allow water to fill for approximately 30 seconds, rotating the chamber slightly to remove any air bubbles in the chamber. Turn off the water supply and close the fill and pressure release valves.

8.8 Re-pressurize the chamber after a total elapsed time of 1 minute (±5 seconds) without pressure. Adjust the regulator as necessary to maintain a pressure of 7930 kPa (1150 psi.). This pressurization time is 2 minutes (±5 seconds). At about 1-1/2 minutes, close the pressure valve and disconnect the drain line from the pressure release valve.

8.9 Release the pressure after 2 minutes (±5 seconds), *while wearing ear protection*, by rapidly opening the pressure release valve (as in 8.6 above).

8.10 Repeat Steps 8.7 through 8.9 eight additional times for a total of ten pressurization cycles. Rotate the pressure chamber back to horizontal for draining.

8.11 Turn off the valve on the nitrogen bottle and open the drain valve. Drain the water from the pressure chamber by slowly opening the pressure valve and allowing the compressed gas in the line to force the water out of the chamber.

8.12 Unbolt the chamber and remove the specimen. Dry the specimen to a constant mass at a temperature of 120°C ±5°C (250°F ±9°F), and allow it to cool to room temperature.

8.13 Place enough of the specimen into the tumbler to fill it approximately half way, and tumble for 1 minute (±5 seconds). Repeat with the remaining portion of the specimen. Separate out any pieces passing the 9.5 mm (3/8 in.) sieve but retained on the No. 4 sieve.. Determine the masses of both the +9.5 mm (3/8 in.) and cumulative -9.5 mm (3/8 in.), +No. 4 sieve particles to the nearest gram (0.002 lb.). Record these values as m_i and $m4_i$ respectively for the "i" number of pressurization cycles completed. Count the number of pieces retained on the 9.5 mm (3/8 in.) sieve and record this number as n_i. Count the cumulative number of pieces passing the 9.5 mm (3/8 in.) sieve but retained on the No. 4 sieve and record this number as $n4_i$.

8.14 Repeat Steps 8.2 through 8.13 for a total of 50 pressurization cycles.

9. CALCULATIONS

9.1 *Percentage Fracture* - Calculate the percentage of fracturing after each ten pressurization cycles as follows:

$$FP_i = 100 * (n4_i/2 + n_i - n_0)/n_0 \quad (1)$$

where FP_i is the percent fractures after "i" pressurization cycles,

$n4_i$ is the cumulative number of pieces passing the 9.5 mm (3/8 in.) sieve but retained on the No. 4 sieve after "i" pressurization cycles,

n_i is the number of pieces retained on the 9.5 mm (3/8 in.) sieve after "i" pressurization cycles, and

n_0 is the initial number of pieces tested.

Report FP values to the nearest integer.

9.2 *Hydraulic Fracture Index* - Calculate the hydraulic fracture index (HFI) as the number of cycles necessary to produce 10 percent fracturing by the following methods:

If 10 percent fracturing is achieved in 50 or fewer cycles, calculate the HFI as a linear interpolation of the number of cycles that produced 10 percent fractures:

$$HFI = A + 10 * [(10 - FP_A)/(FP_B - FP_A)] \quad (2a)$$

where A is the number of cycles just prior to achieving 10 percent fracturing,

FP_A is the percentage of fracturing just prior to achieving 10 percent fracturing, and

FP_B is the percentage of fracturing just after achieving 10 percent fracturing.

If 10 percent fracturing is not achieved in 50 pressurization cycles, calculate the HFI as an extrapolation from no fracturing at 0 cycles through the amount of fracturing at 50 cycles:

$$HFI = 50 * (10/FP_{50}) \quad (2b)$$

where FP_{50} is the percentage of fracturing after 50 pressurization cycles.

Report HFI values to the nearest integer.

9.3 *Percent Mass Loss* - Determine the percent mass loss as follows:

$$ML_i = (100/m_0) * [m_0 - (m4_i + m_i)] \quad (3)$$

where ML_i is the percentage of mass loss after "i" cycles of pressurization,

$m4_i$ is the cumulative mass of the material passing the 9.5 mm (3/8 in.) sieve but retained on the No. 4 sieve after "i" pressurization cycles,

m_i is the mass of the pieces retained on the 9.5 mm (3/8 in.) sieve after "i" pressurization cycles, and

m_0 is the initial mass of the specimen tested.

Report ML values to the nearest integer.

NOTE 12 - When data from more than one specimen are combined for determining final results, the raw data, m_0, n_0, $m4_i$, $n4_i$, m_i, and n_i, should be combined prior to calculation of ML_i, FP_i and HFI.

10. REPORT

10.1 The report shall include the following information and data:

10.2 *Sample Identification:*

10.2.1 Report the person or agency submitting the sample for testing.

10.2.2 List the source or identifying code for the aggregate.

10.3 *Initial Specimen Size:*

10.3.1 Report the particle size range(s) tested as determined in Section 7 of this procedure.

10.3.2 Report the initial mass and initial number of particles as determined in Step 8.1 above.

10.4 *Percentage Fracture*

Report the percentage fracture after each series of ten pressurization cycles.

10.5 *Percentage Mass Loss*

Report the percentage mass loss after each series of ten pressurization cycles.

10.6 *Hydraulic Fracture Index*

Report the hydraulic fracture index for the specimen

10.7 When multiple specimens are tested from the same source and particle size range, list individual and combined specimen values.

NOTE 13 - A graph of fracture percentage versus number of cycles is often useful in presenting the data.

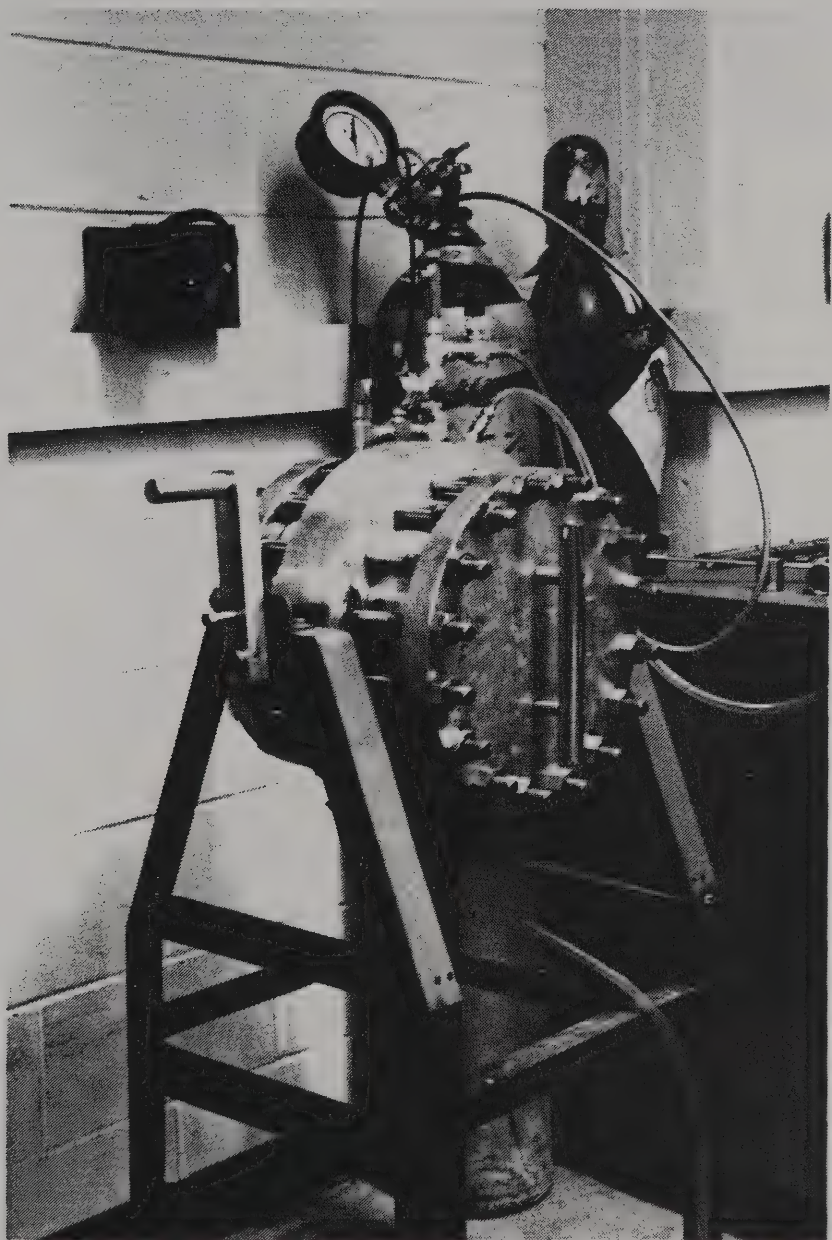
NOTE 14 - An example report form is shown in Appendix C.

11. PRECISION

11.1 *Within-Laboratory Precision* - The precision of results from a single aggregate source appears to depend upon the number of pieces tested. Data is currently being collected in order to determine the within-laboratory precision. Preliminary data is given in Appendix D.

11.2 *Between Laboratory Precision* - Data is currently being collected to determine the between-laboratory precision.

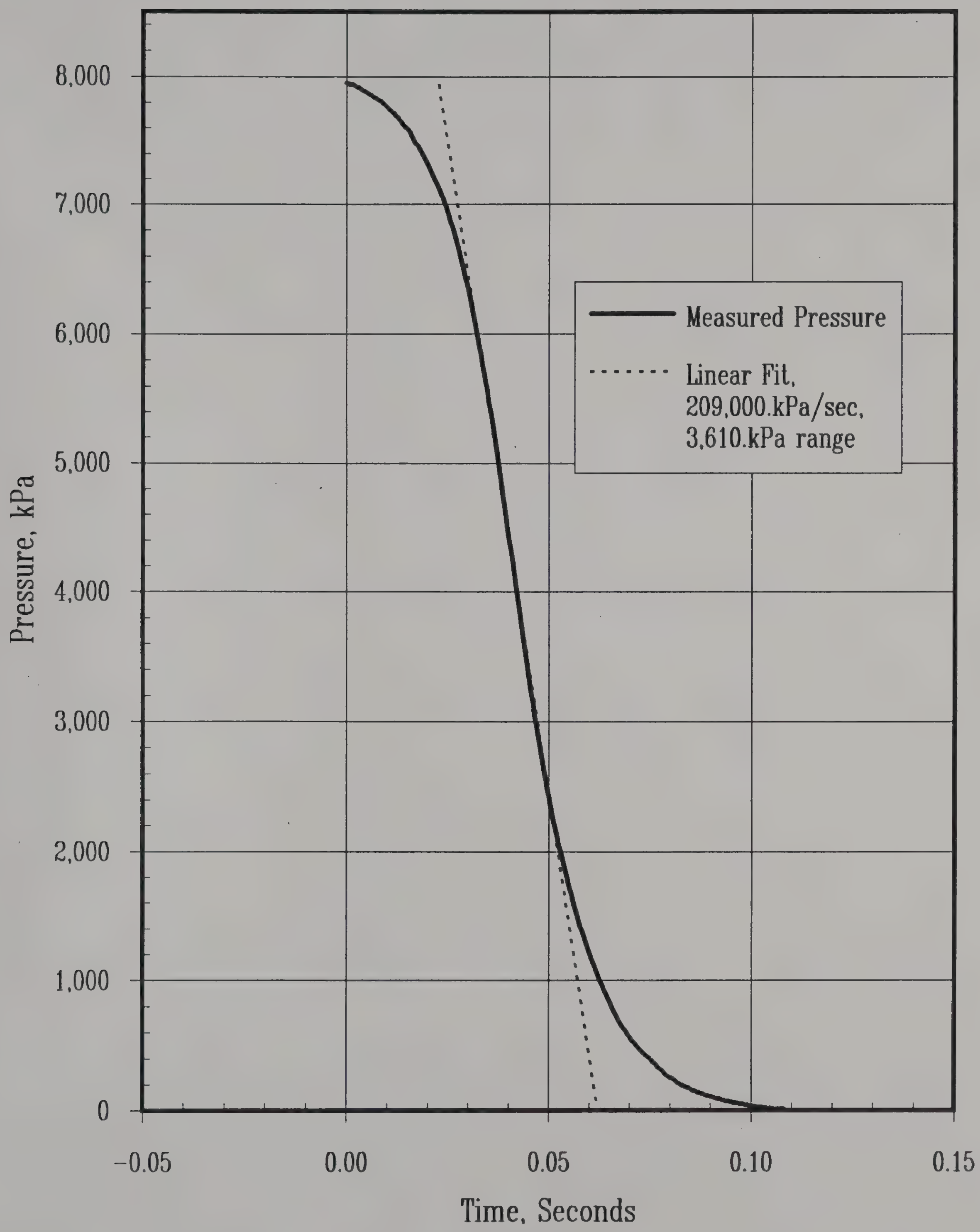
Appendix A
Photograph of Hydraulic Fracture Apparatus



Hydraulic Fracture of Coarse Aggregate

Appendix B
Pressure Release Rate

Following is a typical pressure-time history for the hydraulic fracture apparatus. A linear fit of the central portion of the pressure-time curve shows the curve to be essentially linear over a range of 3,610 kPa (520 psi). The slope of this linear range is 209,000 kPa/sec. (30,300 psi/sec.).


8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Pressure, kPa
-0.05
0.00
0.05
0.10
0.15
Time, Seconds
Measured Pressure
Linear Fit,
209,000.kPa/sec,
3,610.kPa range

Hydraulic Fracture of Coarse Aggregate

Appendix C
Sample Data Sheet

WHFT Data Sheet

Source		Submitted by		Received by		Date	
	Size Range		Initial Mass		Initial	# Particles	
Testing Date	Cumulative # of Cycles	Mass (+9.5mm)	Mass (9.5 to 4.76mm)	Count (+9.5mm)	Count (9.5 to 4.76mm)	% Mass Loss	Percent Fractures
	10						
	20						
	30						
	40						
	50						
						HFI =